Bulletin No. 29.—W. B. No. 219.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

FROST FIGHTING.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

ALEXANDER G. McADIE,
FORECAST OFFICIAL.

WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., March 13, 1900.

Hon. James Wilson,
Secretary of Agriculture, Washington, D. C.

Sir: I have the honor to submit herewith a brief paper on "Frost Fighting," by Mr. Alexander G. McAdie, forecast official, who has devoted much attention to the subject. While the Bureau has but recently issued a bulletin on the same subject, it is believed that the more recent experiments with which Mr. McAdie deals are sufficiently valuable to the extensive fruit interests of California to justify the printing of an edition of five thousand primarily for that State. I therefore recommend the publication of the paper as a bulletin of the Weather Bureau.

Very respectfully,

Willis L. Moore,
Chief U. S. Weather Bureau.

Approved:
James Wilson,
Secretary.

ILLUSTRATIONS.

FROST FIGHTING.

For the past four years the Weather Bureau office at San Francisco has given much attention to the question of protecting the citrus fruit crops of California, particularly of the section south of the Tehachapi, from frosts. It has been estimated that the value of the citrus fruit crop for this section during the year 1899 was in the neighborhood of $7,000,000. It will be readily seen that even if so low a proportion as five per centum of the crop should be lost through frost, the amount involved is still so considerable as to warrant a systematic study of the problem and an endeavor to devise methods minimizing this loss. The problem is of a twofold nature; first, accurate forecasting of the frost period; second, efficient methods of raising the temperature at critical times. The Weather Bureau office at San Francisco has demonstrated beyond criticism that frost can be successfully forecast. Certain fruit growers, and particular credit should be given to the Riverside Horticultural Club for its work in this direction, have both devised and tested methods of smudging, irrigating, heating, covering, etc., of great practical value.

The experience of the past three years warrants the statement that the loss due to frosts in California, hitherto considered unavoidable, can be prevented, and that unless extreme conditions, by which is meant lower temperatures by 5° than have ever yet been experienced in this State, occur, the citrus fruits of California can be successfully carried through the period when frost is likely.

It should be noted at the outset that in many sections for some years past, it has been the practice to call certain areas frostless. Many of the foot-hill sections are advertised as regions in which frost has never been known to occur, but such statements must be received with caution and reliable records insisted upon. For reasons which will be given later in connection with the matter of "Air Drainage," it is plain that places which are exempt from frost one season may be visited with frost at another time and that a slight shifting of the lower air currents is responsible for much of the *streakiness* so characteristic of frost. The surface drainage of the air is not a fixed condition and consequently a region which is frost free under some conditions may be visited with frost when these conditions are slightly altered. In general, then, no section in districts where frost does occur is to be considered as frost proof.

The chief result of the work in California during the past four years is the establishment of the principle that *the formation of frost*

is primarily a matter of air drainage. This principle is shown both in the general pressure distribution over the southwest portion of the country during frost periods, and on a smaller scale in the motion of the surface air currents in certain small areas. A composite map showing the conditions preceding frost was prepared in December, 1899 (see fig. 1[1]). A relief map (see fig. 2) of southern California used in connection with the pressure map will show that the air moving from the north through El Cajon Pass, or over the San Bernardino Mountains, drains southwestward into the districts which are the center of the citrus fruit industry in southern California. When this cold, dry air settles in these lower lands, the temperature near the ground about the time of sunrise will range from 22° to 32°. An important relation, first pointed out by Prof. W. H. Hammon, for forecasting frosts for southern California is this: A wave of falling pressure passes from Montana or Idaho southward across Utah and westward through southern Nevada, thence into Arizona or southern California, and if followed by a rapid rise in pressure, is generally the forerunner of much colder weather in the southern citrus belt. In other words, the usual warm lower air strata are vigorously displaced by cold, dry air; and when the draining ceases and the cold air settles during the period of comparative stillness, frost forms. What is true on a large scale is true on a smaller scale, and a close agreement exists between frost belts or frost streaks and areas of stagnant, cold air. An attempt has been made to plot the channels of air motion and the frost streaks in certain districts. Mr. Frank H. Olmstead, acting for the Los Angeles Daily Times, surveyed the frost localities in Los Angeles, Riverside, San Bernardino, and Orange counties. The survey was necessarily a hurried one; but the correlation of frost streaks and stagnant air was evident. A careful survey should be made by every ranch owner. The writer has urged this matter believing that each grower must work out his own salvation, and that besides studying and practising methods of protection, it is necessary to be familiar with the air drainage of the ranch. In nearly every ranch that the writer has visited there have

[1] The map shown by fig. 1 is a composite of many dates which were followed by heavy or killing frosts within twelve hours. It should be studied carefully by orange growers; and from the beginning of December to the end of the frost season the daily weather maps issued at San Francisco and Los Angeles should be carefully compared with this map. In brief the condition preceding frost is the passage of a low area from Idaho southward across Utah, westward through southern Nevada, and southward into southern California, followed by a marked high. For the most part frosts are due to the movement of the cold air from the northeast. Frosts also occur when a low over southern California moves rapidly southeast, and is followed by a high from northern California. Conversely when air moves from the sea inland, i. e., when the breeze is from the south and west, there is little danger from frost.

been certain well-marked cold spots which, in most cases, were found to correspond with slight depressions in the ground. These three deductions can be drawn from what precedes: (1) Where the air is in brisk motion damage from frost is generally light. (2) Stagnant air, such as exists in low valleys, basins, and inclosed areas, favors frost. (3) As the coldest layer is generally near the ground, it is sometimes advisable to drain downward upper, warm air, displacing surface layers.

In studying frost formation it must be remembered that if there is little aqueous vapor there will be but a small quantity of frost. The temperature of the air, however, may be sufficiently low to seriously injure vegetation. This explains why with low temperatures and low dew-points in certain regions, especially where the radiation of heat is very rapid during the night hours, there are no frosts. It is too dry. Conversely, high dew-points and much moisture in the air sometimes are followed with heavy frosts, although the air temperatures range between 40° and 45°. These points are mentioned to answer the questions which are often propounded, why with low temperatures there is no frost; or why there is no frost one morning and there is frost on a succeeding morning when the temperature is perhaps higher. Distinction must be made between the deposition of the moisture in the air and the temperature of the air itself.

METHODS OF PROTECTING.

Every fruit grower should put himself in communication with the nearest center of distribution of weather forecasts. If possible he should be in daily communication with some Weather Bureau office. Whenever frost warnings are issued for his locality he should carefully determine the temperature and dew-point, as elsewhere described, frequently during the late afternoon and night. A good outfit consists of a metallic thermometer so arranged as to automatically close an electric circuit and ring an alarm whenever the temperature of the air reaches 32°. In addition to a reliable sling psychrometer there should be some small device for testing the motion of the gentle air currents in the orchard. Too much attention can not be given to this question of air motion. Many smudging devices have failed to be effective because of a slow movement of the smoke away from the orchard.

PROTECTIVE METHODS BASED ON MIXING THE AIR.

It is well known that lowlands are visited with frost while hillsides and hilltops escape. Every fruit grower should study the topography of his land and plant accordingly. Wind-breaks are, as a rule, considered detrimental. No hard and fast rule, however, can

be laid down. On a well-known lemon and orange ranch at Santa Paula, the property of Mr. N. W. Blanchard, there are several large wind-breaks which have proven themselves to be of the greatest benefit in protecting fruit from frost. It would almost seem as if the citrus trees within a distance of 50 feet were directly protected by these wind-breaks. By planting a wind-break in the proper place, defects in the topography may be overcome and air currents established where otherwise pools of quiet air would have formed. A wind-break dense enough and so situated as to interfere with any natural circulation and facilitating the formation of still areas or pools would, of course, prove injurious.

PROTECTIVE METHODS BASED ON WARMING THE AIR.

A large number of small fires, advantageously placed, will raise the temperature of the air several degrees. The Riverside Horticultural Club, testing the various methods which were in use in California, came to the conclusion that wire baskets suspended a few feet above the ground, and holding several pounds of coal or charcoal, made an efficient protector. This method was described by Mr. Edward Copely, of Riverside, Cal., in several articles published in the Riverside Press of April, 1896. The cost of the wire basket is about ten cents, and if forty baskets be used to the acre, the cost of fuel will hardly exceed $2.50. To this must be added the cost of labor during the night and succeeding day in refilling the baskets. In the accompanying figures, Nos. 3, 4, and 5, the baskets are shown in position. This method meets with most favor in southern California. The temperature can be raised certainly 3° or 4° with from twenty to forty of these baskets to the acre. It has been suggested that a number of small oil lamps be used with success for this purpose. Oil pots have been used and make a hotter fire, but the deposit of lamp black upon the fruit is objectionable. Some cheap modification of the ordinary plumber's furnace might possibly be devised which, by means of a moderate blast, would produce a high temperature.

PROTECTIVE METHODS BASED ON CLOUD OR FOG BUILDING.

Damp straw, old wood, prunings, manure, etc., when burned briskly furnish an effective smoke, and if the material while burning is doused with water, the result is a dense steamy smoke, which, while trying on human lungs, serves as a screen to prevent loss of heat by radiation and as a barrier between the chilled fruit and a sudden application of heat at the time of sunrise. Wet smudging has been tried in many ways with varying results. There are many reports of failure, and on the other hand, some definite results, showing the good accomplished by this method. Here, as in all other methods of

protection, much will depend upon a careful study of the local conditions. Many a farmer smudges so that some neighbor gets the benefit of his work while his own fruit remains unprotected. All motion of the air should be noted carefully, and this is sometimes difficult where the smoke is very dense. In some orchards sacks of old straw soaked with oil are so distributed as to be available for quick lighting. Portable smudges have also been devised. Fig. 6 illustrates a portable device by Mr. Priestly Hall.

Mr. Hall has made an efficient form of sled operating under the wet smudge principle. Upon a sheet iron sled he has placed a small fire box, consisting of a grate 4 or 5 inches above the bed of the sled, over which pass iron rods bent in the form of an arch, leaving a space for the fire about 14 inches in diameter. This fire box is inclosed in a large corrugated iron box, which has the bed of the sled (about 3 or 4 feet in size) for a bottom, and sides 30 inches high. A door is made in front of the corrugated box to admit fuel to the fire. The box is filled with wet straw or manure and a fire is maintained in the fire box when the machine is in operation. The cost is about $12; one will do for ten acres.

PROTECTIVE METHODS BASED ON IRRIGATION.

Of all methods proposed for the protection of fruit, excepting wire baskets, irrigation has the largest amount of evidence in its favor. It has been tried in many different places with different crops and has generally given satisfaction. Where water is not very plentiful, and this is the case strangely enough in some fruit sections, the method may not always be practicable, but with this exception there are many decided advantages in the generous use of water. Injury from frost depends almost as much upon the condition of the tree as upon the severity of the weather. Critical periods in the life of the tree can be controlled to some degree by the use of water.

Some fruit growers hold that heat is the one thing that is desired at times of frost, and that the best method is that which produces heat by the simplest and least expensive process. Water, owing to its high specific heat, forms an excellent agency for the temporary storage of heat energy. We have seen that in the wet smudge an attempt is made to utilize the latent heat of vaporization, and theoretically this has always seemed the most advantageous method. A modification of the wet smudge is steam piped through an orchard. This experiment was made by the Wright Brothers at Riverside, Cal., with a 35-horsepower boiler and a main pipe 2 inches in diameter, from which, at right angles every 40 feet, pipes three-quarters of an inch in diameter were extended. It is claimed that the temperature was raised 3° whenever the steam was turned on. It is also said that the

coal consumed would not be more than the amount used by the basket method. The estimated expense per acre would be about $75.

The latest device for the protection of citrus fruit against frost combines the good effects of irrigation with heating. This is a method known as the warm water method, tried at Riverside this year. An account of the experiment follows:

Experiment of Mr. Ernest A. Meacham, Riverside, Cal.

On the morning of February 9, 1900, at the Meacham Ranch, a test was made of the Meacham warm water method of protecting citrus fruits against frost. The experiment began at 3:45 a. m., and was conducted in the presence of a number of gentlemen belonging to the Riverside Horticultural Club, nearly all of whom were orange growers.

At 6:30 a. m. the temperature of the ground 100 feet or more away from the boiler was 32°. The temperatures given herewith are those obtained by Mr. McAdie of the Weather Bureau with sling psychrometer No. 70; the number of the dry thermometer was 4487 and of the wet 4486. The plant consists of a 12-horsepower tubular horizontal boiler, laid in a brick furnace, and arranged to deliver water with or without pressure. Cold water enters the bottom of the boiler and is delivered from the top orifice directly into the flume. The fuel used was crude petroleum, of which about 50 gallons were used in three and one-half hours. At the rate of 14 gallons an hour and an estimated cost of a little over 4 cents per gallon, the actual expense of fuel for the experiment was about 60 cents per hour. The oil is burned with a steam jet under pressure. A secondary 6-horsepower boiler, carrying 70 pounds of steam, was used. The oil is thus entirely consumed and makes but little smoke. The whole arrangement is such that not more than two men would be required to attend to all the details.

Fifty minutes from the time of beginning, the water which had an initial temperature of 55.4° was raised 30°. Two sets of temperature records were made, one by Mr. Priestley Hall and the other by Mr. McAdie. In Mr. Hall's test 8 inches of water was run in fifty furrows, which barely ran the water past the ends of the furrows. In the second case 8 miners' inches of water was delivered into twenty-five furrows, thus carrying the heat farther down the furrows than in the first experiment. According to the present laws of California, a miners' inch is $\frac{1}{50}$ cubic foot per second; the second foot is the quantity represented by a stream 1 foot wide and 1 foot deep, flowing at the average rate of 1 foot per second. A cubic foot of water, maximum density, weighs 62.4 pounds; a gallon contains 10 pounds of distilled water at 62°. The data obtained by Mr. Hall were as follows: 5:30 a. m., normal temperature, 34°; normal temperature of water, 60°; temperature of heated water, 92°; at the flume, 92°; 20 rods from the flume, 58°; 40 rods, 52°; temperature of unheated water 40 rods from the flume, 41.5°; vapor condensed on trees early in the morning and more condensed on the trees in the heated plat.

Mr. McAdie's records are as follows: Time, 6:30 a. m., air temperature varying from 34° to 36°; temperature on the ground, 32°; frost was observed on grass blades; initial temperature of water, 55.4°; heated water delivered to flume at 85.2°; in a straight line down a furrow 200 feet from the boiler in the direction of the wind (motion of the air was very gentle) there was a fall in temperature of 14.2°; water vapor was observed rising to a height of about 4 feet; 200 feet from flume, as stated, the temperature of the water was 71°; the temperature of the surface soil 4 inches right and left of the water was 43°; temperature of

the soil 16 inches from the water or in the middle of the ridge, 42.2°. It is presumed that the temperature of the ground had no water been flowing would have been 33°, and it would seem as if the soil itself was warmer by nearly 10°. At the end of a furrow, 660 feet, the temperature of the water was 54°, or there had been a fall of 31° in 40 rods; the temperature of the ground 4 inches from the water, 38°; 16 inches from the water, 36°; temperature of unheated water 50 rods from the flume, 40°.

The approximate value of the plant was $200, and it is estimated that for a plant all equipped sufficient for a ten-acre grove $600 would cover all expenses. See fig. 7.

SPRAYING.

After frost, or rather just before a frost has ended, a spraying device can be used to advantage. Its chief function is to prevent a too rapid warming of the chilled fruit. It is said by horticulturists that even the light coating of ice formed in this way does not seriously damage the fruit. It is very likely that the latent heat of solidification set free by the change from water to ice may play a helpful part; but the chief effect is to prevent a too rapid thawing. In other words, both heat and water should be supplied to the chilled plant slowly, and according to the plant's ability to make good use of the same. At the A. J. Everest ranch at Riverside, Cal., a portion of the grove is protected by sprinklers at the top of fifty-foot masts.

PROTECTIVE METHODS BASED UPON SCREENING OR COVERING.

All screening or covering devices are in effect modified hothouses, and there is no question but that a thorough protection can be accomplished. The expense is the one objection. Screens are made of light materials, namely, canvas, muslin, or light wood work, and have been used with considerable success. At the A. J. Everest ranch an elaborate structure of lath screens is in use, illustrations of which are given herewith (see figs. 8 and 9). There is no question as to the value of the protection, but the expense is considerable, averaging perhaps $400 to the acre. This lath covering may be considered as forming a well ventilated hothouse.

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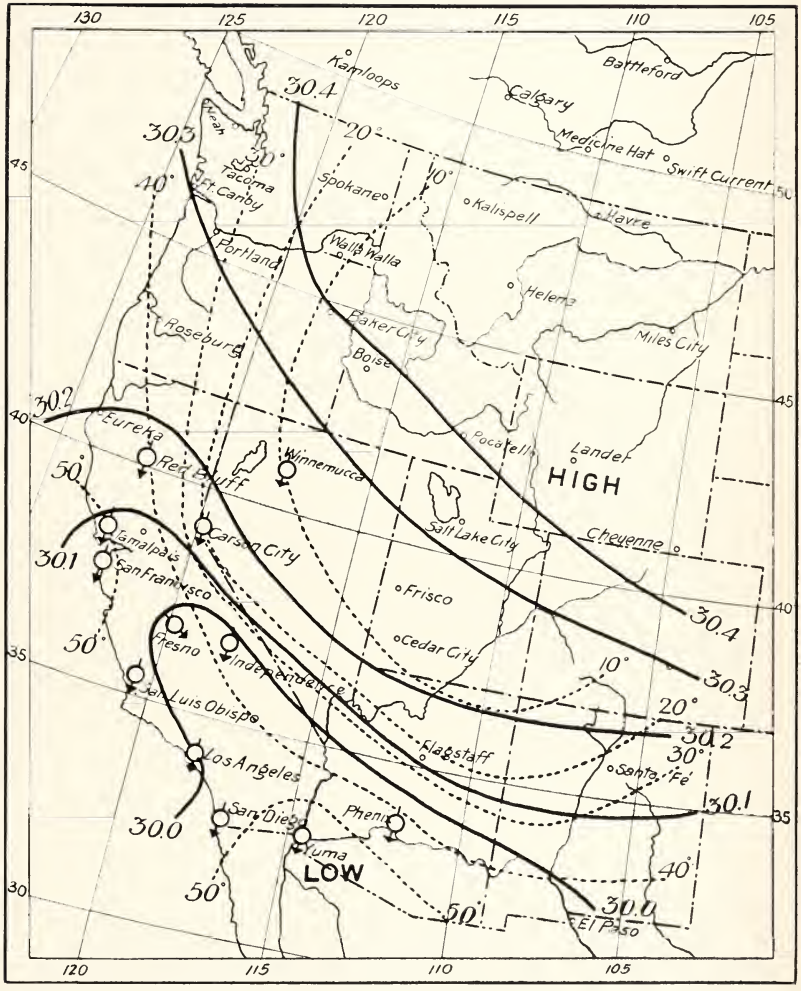

FIG. 1. Composite barometric and thermometric conditions followed by heavy or killing frosts within twelve hours.

FIG. 2. Relief map showing extreme minimum temperatures during frosts injurious to citrus fruits.

FIG. 3. Wire baskets in citrus grove.

FIG. 4. Wire baskets hung from limbs of orange trees.

Fig. 5. Wire baskets in lemon and orange grove.

Fig. 6. Mr. Priestly Hall's device for smudging.

FIG. 7. Eight miners' inches of warm water in orange grove at Meacham Ranch.

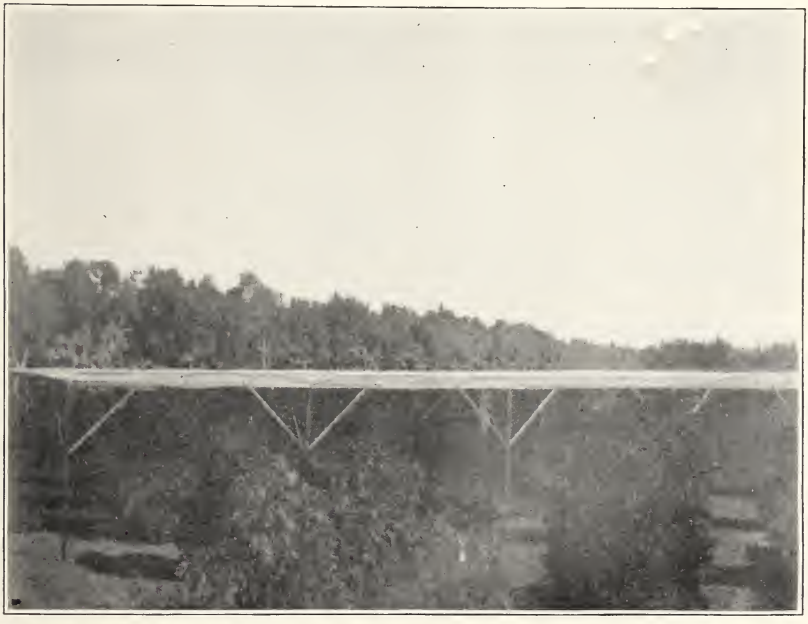

FIG. 8. Lath screen at ranch of Mr. A. J. Everest, Riverside, Cal. (view from above).

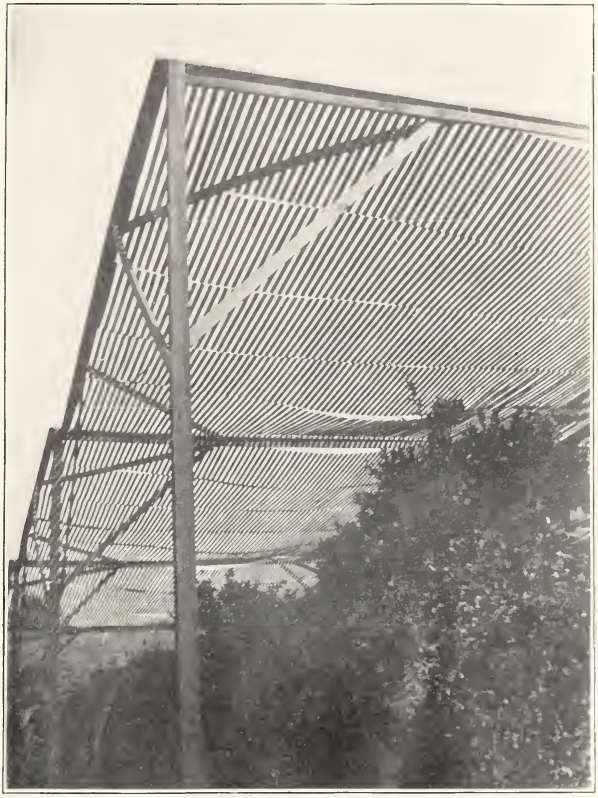

FIG. 9. Lath screen at ranch of Mr. A. J. Everest, Riverside, Cal. (under view).